**ASF Project Report**

Ref: NRA 94-MTPE-05
NASA Ref: 1995-ADRO00194
RTOP: 665-21-02
ADRO Project ID: 164

# "The Circulation and Characteristics of Weddell and Ross Sea Ice"

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November 1997

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## Project Goals

The objectives of the study are to use satellite microwave data from the Southern Ocean for extracting gridded sea-ice parameters such as drift velocity, divergence, shear and opening/closing. These observational data will be used to accurately prescribe boundary conditions in regional model calculations of surface fluxes of heat, salt, freshwater and momentum.

## Progress

Techniques have been developed for gridding and processing radar scatterometer images from ERS-1/2 and NSCAT (provided by Co-I David Long), passive microwave (through collaboration with Jim Maslanik), and SAR data from ERS-1/2 and Radarsat. Gridded ice motion data sets have been generated from each data source (at 3 and 1 day intervals) for an entire year in 1992. Coincident field-deployed GPS/Argos buoy and drifting ice camp locations were used to check on the validity of the tracked drift vectors. Temporally and spatially overlapping SAR motion vector grids have been employed for comparison purposes. Comparisons with ECMWF pressure field data indicate that sea ice drift is forced predominantly by large-scale synoptic pressure fields, and that high frequency motion is driven by passing low-pressure systems and tidal forcing (in continental shelf regions). The latter are significant for new ice production. Synoptic scale sea-ice drift responds rapidly to changes in forcing on timescales of 12 hours or less depending on the location with respect to the coastline. Seasonality of ice drift is linked to the extent of the sea ice within the Weddell and Ross sea basins and the translation of

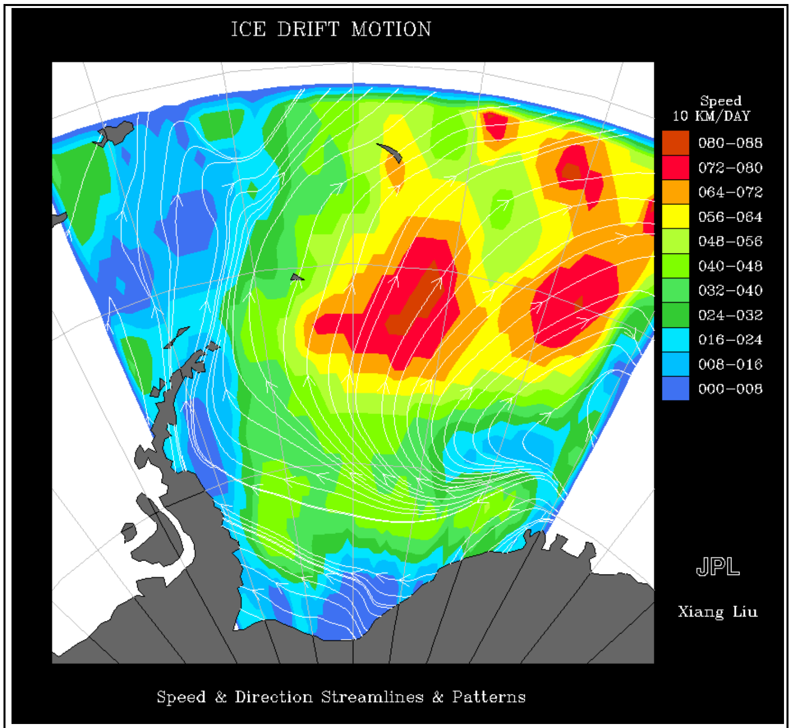


**Figure 1.** Weddell Sea 1992 climatological mean ice drift, derived from July - September SSM/I 1-day ice motion vectors. Colors indicate spatial variations in the drift speed and the white arrows indicate streamlines of drift. Convergence and divergence are indicated by narrowing or spreading of the streamlines, respectively.

internal ice stresses through the pack ice.

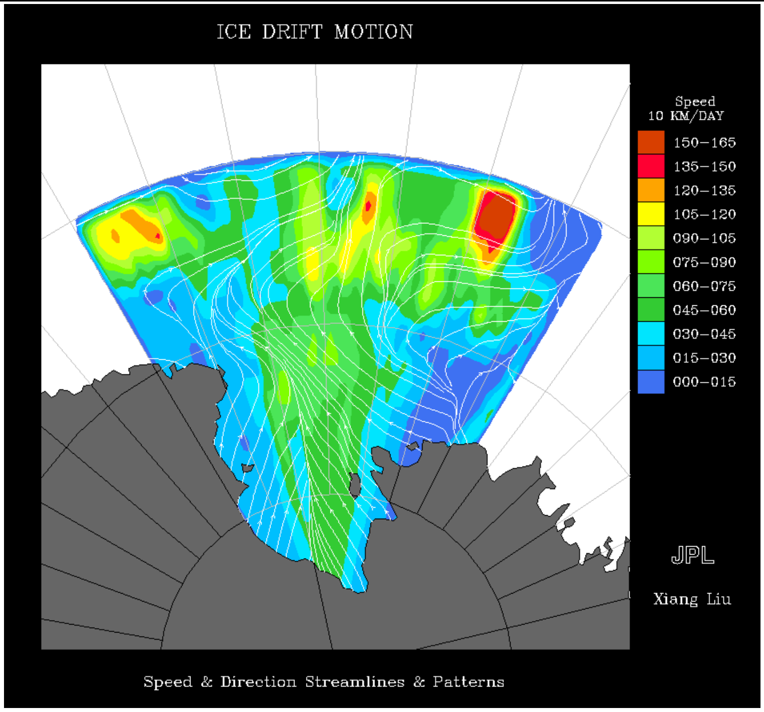


**Figure 2.** Ross Sea climatological mean ice drift, derived from July-September ERS-1 Scatterometer 3-day ice motion vectors in 1992. As in Figure 1, colors indicate spatial variations in the drift speed and the white lines and arrows indicate the direction and streamlines of drift.

**Results and Achievements**

Climatological summaries of kinematic and dynamic parameters have been derived which are being compared with numerical model simulations of sea ice in the Weddell and Ross Sea sectors. Since these are scale dependent, a grid spacing (~100 km) has been chosen to be consistent with current model grids. The grid resolution may be adjusted and made finer at a future date, as dependent upon the accuracy and precision of the tracked large-scale sea-ice drift. Figures 1 and 2 indicate summaries of austral winter three-monthly climatologies of ice drift in the Weddell and Ross Sea sectors of the Southern Ocean. The Weddell Gyre is clearly resolved in Figure 1 with the key characteristics of the cyclonic (clockwise) gyre motion captured. Color gradients indicate acceleration of the sea ice as it escapes the coastal entrapment of the Antarctic peninsula and enters the Antarctic Circumpolar Current (ACC). In Figure 2 the extent of the Ross Sea Gyre is delineated with ice leaving northwards, to turn east and flow into the Amundsen Sea. A distinctive convergence zone occurs along the central axis of the Ross Sea along 190° E. This is the location where old (perennial) ice recirculating from the Amundsen Sea coastal region meets newly formed ice driven northwards away from the Ross ice shelf by strong katabatic winds.

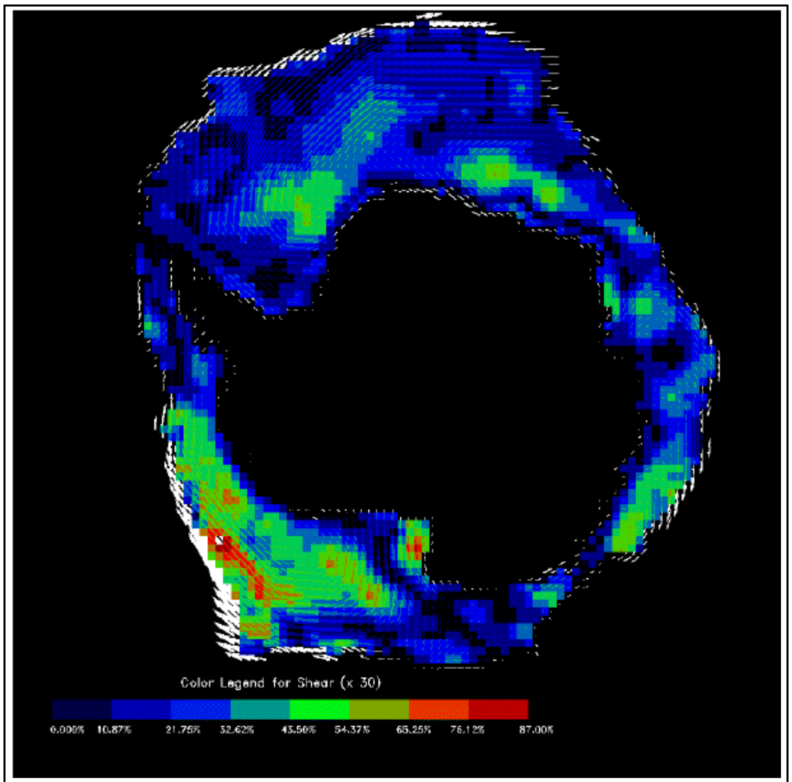


**Figure 3.** Climatological net shear strain (%/day) for the 3 month austral winter period Jul. - Sept., 1992.

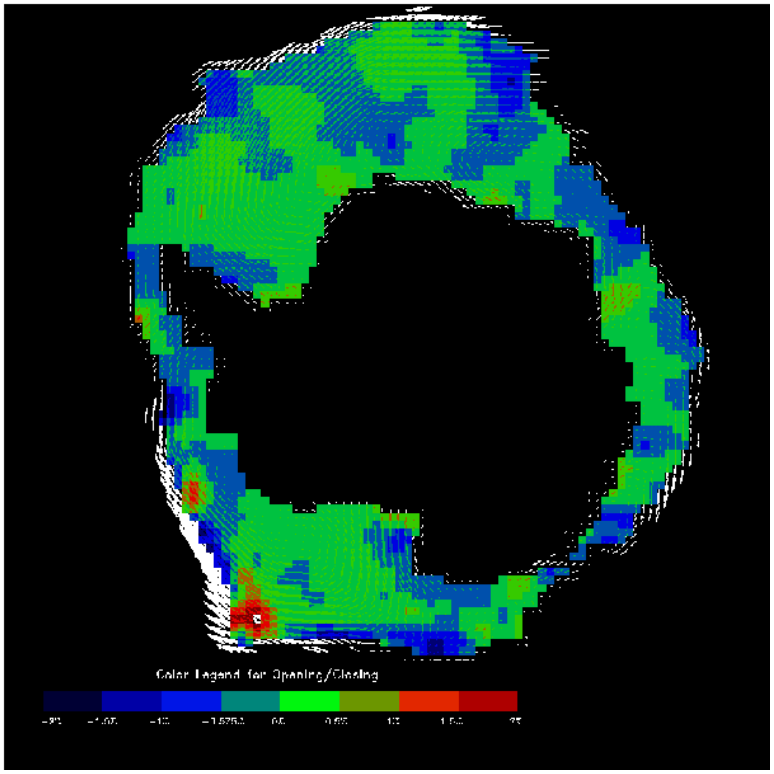


**Figure 4.** Climatological net 1-day opening/closing during Jul. - Sept., 1992. Color scale indicates opening and closing in boxes of 10 x 10 pixels each averaged over an area of 4 boxes. Individual pixel spacing is 8.8 km.

Figures 3 and 4 show dynamical summaries corresponding with the identical 3-month mid-winter period (July - September, 1992). Mean 1-day shear strain (strain invariant $E_{II}$) is represented in a colorized gridded plot overlaying the climatological mean 1-d motion field of the sea ice. Regions of significant climatological shear occur primarily in the central Weddell and Ross gyres. High shear also helps delineate the axis of the Antarctic divergence in some parts of the sea ice cover. In these regions, the separation between the coastal "east wind drift-" and ACC-dominated drift regimes are characterized by zonally extended regions of intense shear. Other important zones of high shear occur in the Ross Sea sector. At the western margin of the Ross Sea, rapidly produced new ice exits the Terra Nova Bay polynya in the coastal current, with large shear values captured along the coast. In addition, at the northern limb of the Ross Gyre, where some of the highest sea ice drift velocities are experienced, the largest pole of winter shear strain is measured.

Figure 4 shows the resulting opening and closing computed from the ice deformation. Areas of sustained climatological opening/ closing are consistent with areas of production of new sea ice, and with zones of intensified ridging (also observed in SAR images). Net opening is observed in a number of known regions of persistent coastal polynyas. These are found off the Amery ice shelf, in Terra Nova Bay, off Cape Norway and the Filchner-Ronne ice shelf, and around parts of Wilkes Land. The two most intense offshore openings occur in the region of maximum sea-ice extension in the Ross Sea, and in a small area of the Amundsen Sea.

Numerical model simulations were undertaken in the Weddell Sea (over a period of 16 years: 1979-1995) in conjunction with visitor Martin Kreyscher from the Alfred Wegener Institute (AWI). A variant of the AWI coupled dynamic-thermodynamic code was used to simulate ice dynamics and ice production rates in the Weddell Sea. Comparison between tracked ice-motion fields and simulations indicate a large degree of variability in both seasonal and annual mean ice drift. This variability in turn appears to be strongly coupled to anomalies in sea-level pressure and meridional wind stress observed in ECMWF meteorological analysis.

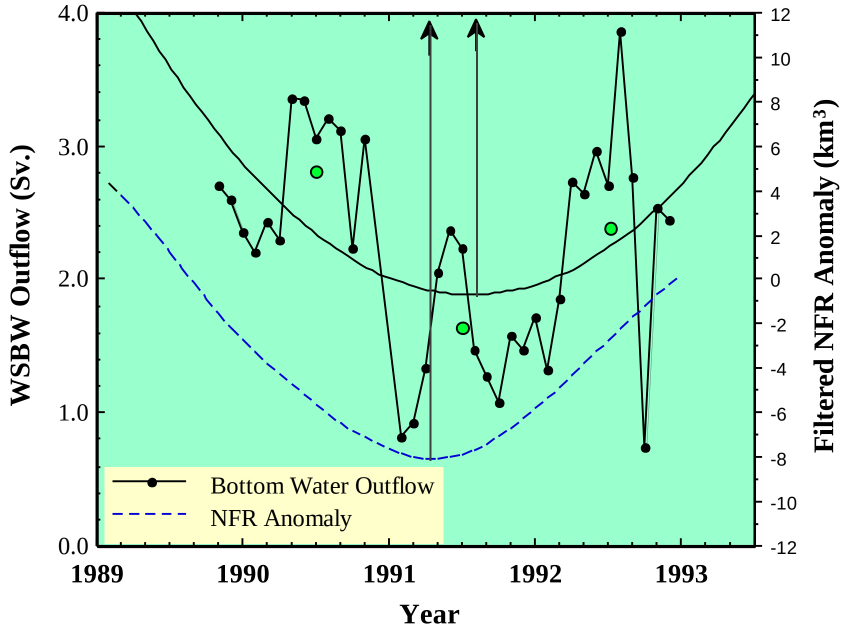


**Figure 5.** Comparison between filtered Net Freezing Rate (NFR) anomaly and Weddell Sea bottom water outflow at Joinville Island (after Fahrbach et al., 1995). Arrows indicate lag between these interannual cycles.

Dynamic-thermodynamic model simulations reproduce seasonal variability in ice drift and indicate that there is significant interannual variability in Weddell Sea ice formation, and drift and on the El Niño Southern Oscillation (ENSO) timescale, with a period of ~ 8 years. This variability is consistent with the eastward passing of a spatial pattern of linked atmospheric and sea-surface temperature anomalies, similar to that characterized by White and Peterson (1996) as an "Antarctic Circumpolar Wave". Linked to these fluctuations are periods during which open water production in coastal polynyas and climatologically divergent regions is either enhanced or decreased. The process of enhanced northwards ice drift and hence polynya ice growth is consistent with changes in the atmospheric circulation patterns and meridional wind stress. Changes in ice dynamics on these timescales regulates the amount of ice-shelf polynya ice formation, in particular along the Ronne ice shelf. Appearance of a large polynya in this region was previously documented in both SAR and scatterometer data. The timing and duration of the opening of the Ronne ice-shelf polynya system is strongly regulated by the meridional wind stress, since this carries ice northwards away from the ice-shelf front. Divergence and open-water formation in this location enables ice production is excess of 7 m per year, in contrast to the typical thickness of ~1m ice found elsewhere in the Weddell Sea. The measured outflow of cold Antarctic bottom water appears to be closely related to the ice production and salt rejection during polynya formation events. Figure 5 shows the relationship between the seasonal and annual mean Weddell Sea Bottom Water outflow [Fahrbach *et al.*, 1995], and the 3-7 year pass-band filtered Net Freezing Rate (NFR) anomaly, calculated with the AWI dynamic-thermodynamic sea-ice model [Kreyscher, *pers. comm.*].

The upper fitted 2nd order polynomial curve in Figure 5 shows the smoothed long-term variations in Weddell Sea Bottom Water outflow, superimposed on the seasonal mean monthly outflow (jagged black line) and mean annual outflow record (represented by large solid green circle symbols). The lower dashed blue net freezing rate anomaly cycle is calculated over the period 1986-1993 by removing the annual mean cycle from the monthly integrated ice production record within a number of model grid cells in the Southern Weddell Sea (spanning the region of Ronne polynya formation). This dashed curve is filtered using a 3-year admittance window and indicates a 4-year peak-to-peak anomaly cycle in ice production in response to changes in the forcing over these timescales. The lag between ice production and outflow is explained by the time taken in this case for the water to flow northwards from the polynya region to Joinville Island where it was monitored. In summary, Figure 5 implies that the bottom water flowing out of the Weddell Sea into the global abyssal ocean, is controlled by climate-regulated sea-ice dynamics. Since the Weddell Sea is the primary Antarctic bottom water source region, it is anticipated that interannual anomalies in outflow have a considerable impact on global thermohaline circulation.

Further, more comprehensive conclusions will be drawn with high-resolution Radarsat results in combination with time series of motion data obtained from scatterometer and passive microwave instruments for the entire period corresponding to the model results.

**Plans**

The current task is to incorporate recently acquired Radarsat frames, collected over the Ronne-Filchner polynya formation region, into the gridded analysis of opening and closing. Temporally overlapping wide-swath and standard beam frames will be acquired to enable short-term, and high-resolution opening and closing regulated ice production to be assessed. Tracking short-term ice drift will enable both sustained and short timescale forcing of dense water formation to be taken into account. Further wide-swath data acquired over the Ronne ice shelf polynya system will be used to investigate the comparative frequency of opening and closing events throughout the year in that location. Further data acquired along the Ross ice shelf polynya front will allow a similar study to be undertaken.

**Requirements**

Further data are required with which to be able to characterize a complete seasonal cycle of sea ice growth and decay in the areas of polynya ice formation in the Weddell and Ross Seas. No consistent, ongoing (i.e. standing order) data request has resulted in consistent periodic sampling of any region in the Southern Ocean, and a concerted effort must be made to satisfy this requirement. This should be made a high priority particularly within the McMurdo receiving station mask where direct downlink is possible. Tape recorded data will be requested in areas of the Weddell Sea not covered by the fringe of the McMurdo mask.

**Peer Reviewed Publications**

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**Published Conference Papers and Reports**

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**Brief Comments**

Data quality from ASF is so far good and the responsiveness to problems is excellent particularly in regards to data request and ordering, where numerous pitfalls are present. Adaptation of Mosaicking tools  is necessary to flexibly enable conversion of individual frames in to strips of images. Rick Guritz has so far been very helpful in regards to conversion of some STEP routines for use with both Radarsat and ERS-1/2 data. But all STEP Tools should be flexible enough to use on both CEOS datasets.

For Antarctic data users without the benefit of RGPS, software is required to find overlapping image pairs which may be used to track sea ice. Software for Eulerian tracking must be developed and made available to all users to generate results from these image pairs. Both should be made available as part of the STEP software tool packages.